Exhaust Gas

Crops

Identification of Petitioned Substance

Chemical Names:
Exhaust gas

Other Name:
Vehicle exhaust
Combustion flue gas

Trade Names:
N/A

CAS Numbers:
630-08-0 (Carbon monoxide)

Other Codes:
211-128-3 (EINECS, carbon monoxide)

Summary of Petitioned Use

The petition before the National Organic Standards Board (NOSB) is to add exhaust gas as an allowed synthetic substance in organic crop production (§205.601) for underground rodent control. There are no related rulings offered by the National Organic Program (NOP) regarding the use of exhaust gas or pure carbon monoxide in organic crop or livestock production from which comparisons may be drawn.

The petitioned use of exhaust gas for underground rodent control necessitates an evaluation of the substance against the criteria in the Organic Foods Production Act (OFPA). This process involves consideration of the chemistry of the substance in the terrestrial environment, the potential toxicity to humans, beneficial soil microorganisms, natural rodent predators and non-target burrowing animals, as well as alternative substances and practices available to organic crop producers.

Characterization of Petitioned Substance

Composition of the Substance:

Exhaust gas is a complex mixture of numerous volatile compounds. Molecular nitrogen (N_2), water vapor (H_2O) and carbon dioxide (CO_2) are the largest constituents of combustion gas. A small portion of exhaust gas is comprised of noxious and toxic substances, including carbon monoxide (CO) and hydrocarbons (HC) from incomplete combustion, nitrogen oxides (NO_x) from excessively high combustion temperatures, particulate matter (soot) arising from incomplete combustion of liquid fuel droplets near the fuel injector, and methane (CH_4) produced in small quantities through combustion reactions occurring in internal combustion engines (Wallington, 2008). Variable quantities of sulfur dioxide (SO_2), which poses a number of human and environmental health risks, are produced during the combustion of fuels containing sulfur. SO_2 formation is primarily associated with the burning of coal, oil and, to a lesser extent, diesel (Elliott, 1955; US EPA, 2009). Small quantities of aldehydes and alcohols may also result from partial oxidation of the hydrocarbons in the fuel.

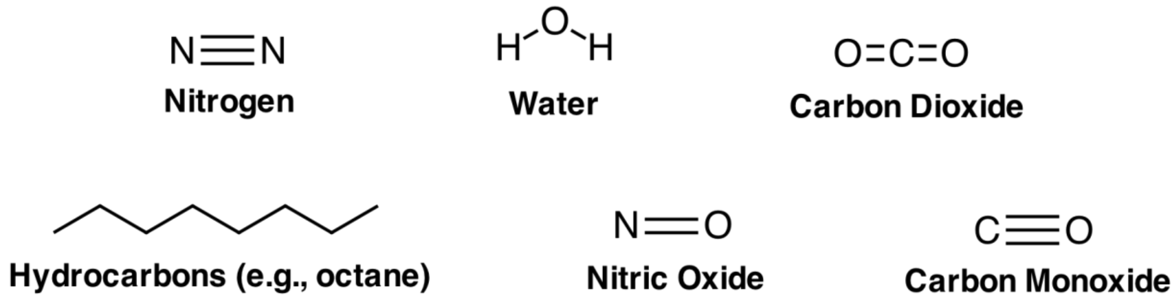

Figure 1. Exhaust gas consists mostly of nitrogen, water vapor and carbon monoxide, as well as smaller quantities of unreacted hydrocarbons, nitrogen oxides (e.g, NO) and carbon monoxide.

The proportions of different exhaust gas components vary depending on the fuel type used for combustion. In gasoline-based engines, nitrogen, carbon dioxide and water constitute approximately 98% of the gaseous mixture, while HC, NO_x, CO and, in some cases SO_2, make up the remaining 2% (Figure 2) (Volkswagon, 2000). Diesel vehicle exhaust gases contain a combined total of 0.3% of SO_2, HC, NO_x, CO and particulate matter, in addition to the larger percentages of nitrogen, carbon dioxide, water and oxygen (combined 99.7%) (Volkswagon, 2000).

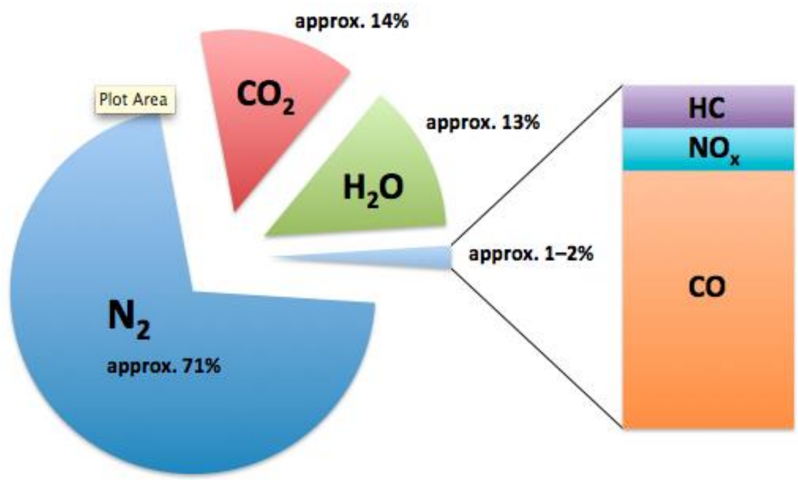

Figure 2. Gasoline-based exhaust gas primarily consists of nitrogen, carbon dioxide and water vapor. *Adapted from* Volkswagon, 2000.

According to the petitioner, the Kohler Co. engines used to power H&M Gopher Control equipment are certified according to the CARB Tier III and EPA Phase III non-road engine standards. These standards specify HC, NO_X and CO emissions standards. The certification limits are as follows (Kohler, 2013):

CARB: 10 grams HC + NO_X/kilowatt hour (kW-hr) and 549 grams CO/kW-hr for model CH270
8 grams HC + NO_X /kW-hr and 549 grams CO/kW-hr for CH440 and CH640 models
EPA: 10 grams HC + NO_X /kW-hr and 610 grams CO/kW-hr for the CH270 model
8 grams HC + NO_X /kW-hr and 610 grams CO/kW-hr for the CH440 and CH640 models.

It should be noted that the certification limits quoted above are specifically relevant to a new internal combustion engine. Engine efficiency is known to change over time, so he amount of NO_X and CO produced may increase with continued use of engines in rodent control devices.

Source or Origin of the Substance:

Exhaust gas is generated through the combustion of fuels, such as gasoline, diesel, and natural gas. Combustion is generally defined as a chemical reaction that occurs when oxygen (O_2) combines with other substances to produce heat and usually light (Merriam-Webster, 2014). The combustion process in an internal combustion engine involves the reaction of petroleum fuel (i.e., hydrocarbons) with an oxidizer (O_2

in air) initiated by a spark in the combustion chamber. See Evaluation Question #2 for details regarding the combustion of gasoline in internal combustion engines used for rodent control devices.

Properties of the Substance:

Because of the similar levels of nitrogen (N_2), oxygen (O_2) and water vapor (H_2O), ambient air can be used to approximate the physical/chemical properties of exhaust gas mixtures. Compared to the composition of air, exhaust gas contains increased concentrations of H_2O and carbon dioxide (CO_2). The combustion products (primarily CO_2) displace O_2 to a concentration ranging from a few percent up to approximately 17%; for comparison, 21% of ambient air consists of O_2 (DieselNet, 2011). Because exhaust gas consists of volatile organic and inorganic chemicals, the properties of the mixture are similar to that of the individual components. With the exception of water, exhaust gas chemicals are characterized by:

- low molecular weight,
- gaseous form,
- low boiling points,
- low heats of vaporization,
- high vapor pressures,
- limited solubility in water and organic solvents at the temperatures exhaust gas is produced,
- limited adsorption to soil particles due to volatility, and
- low density at ambient temperatures and pressures.

Data Sources: HSDB, 2011; HSDB, 2010a; HSDB, 2010b.

Specific Uses of the Substance:

Carbon monoxide in the pressurized exhaust gas is used to kill burrowing rodents. According to the petitioner, pressurized exhaust gas systems have been used throughout the United States to treat dry land pastures and range lands infested with ground squirrels and prairie dogs. Exhaust gas systems have been used to treat fields containing alfalfa, grape vines, almonds, walnuts, cherries, blueberries and grass seed. Likewise, the horse industry has used exhaust gas systems to eliminate burrowing rodents in paddocks and pastures. These rodent control treatments have also been conducted in private resident yards, public rights of way, parks and schools yards (H&M, 2012).

Processes for harnessing the energy and fertilizing capacity of exhaust components have been developed. Carbon monoxide in captured exhaust gas can be converted to fuel ethanol using genetically engineered microorganisms (Bullis, 2010). In addition, farm trials are being conducted on fertilizer systems designed to infuse machinery exhaust gases into agricultural soils to stimulate the metabolism of ammonia oxidizing bacteria and enhance the overall productivity of treated fields (Heard, 2013; Boy, 2012). These more recent uses of exhaust gas have yet to be widely adopted in industrial and agricultural sectors.

Approved Legal Uses of the Substance:

Because rodent control devices produce exhaust gas mixtures to fumigate rodent burrows, the active ingredient carbon monoxide is not currently regulated as a rodenticide under the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA). However, any device bearing claims to control pests (insects, weeds, rodents or microorganisms) must be registered with US EPA. The petitioner, H&M Gopher Control, stated that all information concerning the rodent control exhaust gas system, including the patent application, was submitted to US EPA in 2006. Following submission and review, the petitioner was issued an EPA establishment number (83419-CA-001), and is required to assign each unit a serial number and maintain records of entities purchasing the commercial exhaust gas units. Data is reported to US EPA on an annual basis (H&M, 2012).

The State of California legislature approved the use of carbon monoxide for vertebrate pest control, effective January 1, 2012 (AB 634, 2011). Prior to the passage of this bill it was illegal to kill any animal, including vertebrate pests, using carbon monoxide in California. The California legislative decision suggests that use of exhaust gas rodent control systems is legal in states that do not explicitly prohibit the use of carbon monoxide for vertebrate pest control.

Action of the Substance:

Although exhaust gas contains small quantities of numerous toxic chemicals, the acute lethality of exhaust gas to burrowing pests is specifically related to the carbon monoxide (CO) content. The positive pressure of exhaust gas expels the air when pumped into burrows, effectively replacing the air with an atmosphere containing toxic concentrations of carbon monoxide (H&M, 2012). CO competes with oxygen for binding to hemoglobin, the body's primary oxygen transporter complex. Therefore, CO poisoning is largely the result of the formation of carboxyhemoglobin (COHb), which impairs the oxygen carrying capacity of the blood (HSDB, 2010b; NIST, 2008).

Combinations of the Substance:

The petitioned substance represents a mixture of chemicals ranging from benign (e.g., nitrogen and water vapor) to noxious and toxic (e.g., carbon monoxide and nitrogen oxides). For the petitioned use pattern as an underground rodent control substance, exhaust gas is not combined with any other synthetic or natural substance to perform the intended function.

Status

Historic Use:

There are no historic uses of exhaust gas or carbon monoxide in organic production. Exhaust gas is produced in the internal combustion engines of tractors and other farm equipment used to produce food commodities and animal feed on commercial farms, both organic and conventional. Conventional farm operators and pest control professionals treating public and private lands have utilized the poisonous aspects of exhaust gas for the control of burrowing rodents. Our literature searches did not identify any historic uses of pure carbon monoxide in organic or conventional agriculture.

Organic Foods Production Act, USDA Final Rule:

Neither of the terms "exhaust gas" or "carbon monoxide" are mentioned in the Organic Foods Production Act of 1990 (OFPA) or the National Organic Program Final Rule, 7 CFR Part 205. Although not directly related to crop production, the Facility Pest Management Practice Standard states that the producers or handlers of an organic facility may control pests through (7 CFR 205.271(b)):

1) Mechanical or physical controls including but not limited to traps, light, or sound; or
2) Lures and repellents using nonsynthetic or synthetic substances consistent with the National List.

International

Exhaust gas and/or pure carbon monoxide are not explicitly permitted for use as rodenticides in any form of organic production by the following international organizations:

- Canadian General Standards Board (CAN, 2011a; CAN, 2011b),
- Codex Alimentarius Commission (Codex, 2013),
- European Union (EC, 2008),
- Japanese Ministry of Agriculture, Forestry and Fisheries (JMAFF, 2005),
- International Federation of Organic Agriculture Movements (IFOAM, 2014), and
- United Kingdom Soil Association (Soil Association, 2014).

Of the international organizations included in this review, the Canadian General Standards Board provides the most explicit guidance concerning underground rodent control. According to the General Principles and Management Standards, "mechanical and sticky traps are permitted, as are natural repellents in accordance with CAN/CGSB-32.311, Organic Production Systems – Permitted Substances List" for the control of "rodents and other destructive pests" (CAN, 2011a). Baits for rodent traps should not consist of synthetic substances; however, cholecalciferol (vitamin D_3) may be used when prescribed rodent control practices have failed, and sulfur smoke bombs are allowed for rodent control when full pest control programs are maintained but temporarily overwhelmed (CAN, 2011b). It should be noted that smoke bombs are no longer allowed in organic production in the United States (USDA, 2011b).

Evaluation Questions for Substances to be used in Organic Crop or Livestock Production

Evaluation Question #1: Indicate which category in OFPA that the substance falls under: (A) Does the substance contain an active ingredient in any of the following categories: copper and sulfur compounds, toxins derived from bacteria; pheromones, soaps, horticultural oils, fish emulsions, treated seed, vitamins and minerals; livestock parasiticides and medicines and production aids including netting, tree wraps and seals, insect traps, sticky barriers, row covers, and equipment cleansers? (B) Is the substance a synthetic inert ingredient that is not classified by the EPA as inerts of toxicological concern (i.e., EPA List 4 inerts) (7 U.S.C. § 6517(c)(1)(B)(ii))? Is the synthetic substance an inert ingredient which is not on EPA List 4, but is exempt from a requirement of a tolerance, per 40 CFR part 180?

(A) The burning of some fuels, particularly coal, oil and, to a lesser extent, diesel, may result in the formation of exhaust gas containing small amounts of sulfur oxides (SO_X). Therefore, exhaust gas may be considered a sulfur-containing substance.

(B) Exhaust gas is a complex mixture containing the active ingredient carbon monoxide, and is therefore not a synthetic inert ingredient. US EPA has not established a tolerance for exhaust gas, or the active ingredient carbon monoxide, due to the rapid dissipation of the substance and lack of direct pesticide uses in the production of agricultural commodities.

Evaluation Question #2: Describe the most prevalent processes used to manufacture or formulate the petitioned substance. Further, describe any chemical change that may occur during manufacture or formulation of the petitioned substance when this substance is extracted from naturally occurring plant, animal, or mineral sources (7 U.S.C. § 6502 (21)).

Exhaust gas is generated from the combustion of fuels. Combustion is generally defined as a chemical reaction that occurs when oxygen (O_2) combines with other substances to produce heat and usually light (Merriam-Webster, 2014). The combustion process in an internal combustion engine involves the reaction of petroleum fuel with an oxidizer (O_2 in air) in a combustion chamber. An ignition source, such as an open flame or spark plug in automobile engines, is required to initiate the combustion reaction. Possible fuel sources include, but are not limited to, gasoline, diesel, hydrogen, methane (natural gas), and propane. Gasoline-based engines, such as those included in the current petition, function according to the Otto cycle and facilitate combustion by (MIT, 2002; NASA, 2014):

1) ingesting a mixture of fuel and air;
2) compressing the gaseous mixture;
3) igniting the mixture (spark plug), thus effectively adding heat through the conversion of chemical energy into thermal energy;
4) allowing the combustion products (i.e., exhaust gas) to expand;
5) expelling the exhaust gas; and
6) replacing the ejected exhaust gas with a new charge of fuel and air.

According to the petitioner, the devices used for burrowing rodent control capture the exhaust gas produced in internal combustion engines, route it through a set of cooling coils and into the intake ports of a compressor. The exhaust gas is then pressurized and injected into the burrow of the target rodent pest using two, four or six injection hoses (H&M, 2012).

Evaluation Question #3: Discuss whether the petitioned substance is formulated or manufactured by a chemical process, or created by naturally occurring biological processes (7 U.S.C. § 6502 (21)).

According to the NOP final rule, synthetic substances are "formulated or manufactured by a chemical process or by a process that chemically changes a substance extracted from naturally occurring plant, animal, or mineral sources" (7 CFR 205.2). Exhaust gas is generated through the burning of fossil fuels, which are ultimately derived from plant sources. The chemical reaction producing exhaust gas involves the exothermic (heat releasing) oxidation of hydrocarbons within the fuel to carbon dioxide. Unreacted hydrocarbons (HC), partially oxidized hydrocarbons (CO) and other pollutants (NO_X and particulate matter) are minor components of exhaust gas mixtures produced through the combustion of gasoline. Despite their natural origin, fossil fuels are generally categorized as synthetic substances due to the chemical refinement that occurs during production. Exhaust gases generated through the combustion of fossil fuels would therefore be considered synthetic.

<u>Evaluation Question #4:</u> Describe the persistence or concentration of the petitioned substance and/or its by-products in the environment (7 U.S.C. § 6518 (m) (2)).

Due to the volatile nature of the chemical constituents, exhaust gas emissions initially impact the atmosphere. The environmental fate of exhaust gas is directly related to the fates of individual constituents in the gaseous mixture. This section summarizes technical information related to the persistence of exhaust gas constituents in soil, water and the atmosphere.

The oxidized components of exhaust gas include carbon monoxide, carbon dioxide, nitrogen oxides and sulfur oxides. Carbon monoxide (CO) is the active component of the petitioned substance exhaust gas. CO generally enters the environment from the burning of fuel oils and is released during some natural processes. Once released to the atmosphere, CO remains in the air for approximately two months (ATSDR, 2012). The gaseous substance is broken down in the atmosphere by reacting with other chemicals and is oxidized to carbon dioxide (CO_2). When present in soil, microorganisms metabolize CO to form CO_2. CO does not accumulate in plants or the tissues of animals (ATSDR, 2012). CO_2 can be long-lived in the atmosphere, with half-lives ranging from five to 200 years, depending on the model parameters (IPCC, 2001; Moore, 1994). The oceans and terrestrial vegetation absorb large quantities of excess atmospheric CO_2 (HSDB, 2010a).

Emissions of nitrogen oxides (NO_X) from combustion are primarily in the form of nitric oxide (NO) (US EPA, 1999). Except for small amounts of NO emitted from soils, lightning and natural fires, NO is largely generated by human activity. NO released to the atmosphere is rapidly converted to nitrogen dioxide (NO_2) which undergoes a photochemical reaction with the O_2 in air to form ozone (O_3) and regenerate NO. NO_2 also produces nitric acid (HNO_3) in the presence of water (US EPA, 1999). Nitrous oxide (N_2O) is another NO_X emitted in exhaust gas, and has a half-life of 100 to 150 years in the atmosphere (US EPA, 1999). The small amounts of sulfur dioxide (SO_2) in exhaust gas may be removed from the atmosphere by oxidation, wet and dry deposition, absorption by vegetation and soil, and dissolution into water. In the presence of water, SO_2 generates sulfuric acid (H_2SO_4). Atmospheric residence times for SO_2 range from one to five days (Alberta, 2003).

Unreacted hydrocarbons (HCs) in exhaust gas are primarily short-chain (four or five carbon) alkanes and alkenes and some aromatics such as polycyclic aromatic hydrocarbons (PAHs). As minor components of exhaust gas, these volatile HCs from gasoline enter the atmosphere where photochemical oxidation is the primary removal process; half-lives for these photochemical reactions range from one to ten days depending on the HCs in the mixture. (ATSDR, 1995). Biodegradation of gasoline HCs by a variety of microorganisms is an important degradation process in surface waters, soil and groundwater. The bioaccumulation potentials of HCs range from high for alkanes (BCF = 100–1,500), moderate for aromatics (BCF = 20–200) and low for alkenes (BCF = 10), with some variation within these groupings depending on molecular weight (ATSDR, 1995).

Although unreactive, particulate matter generated during combustion behaves much like gas molecules in the atmosphere; particles may be transported over long distances and potentially penetrate the stratosphere. Removal rates for particulate matter are estimated to be low, resulting in atmospheric lifetimes of several days (WHO, 1996). However, aggregation of particles in the atmosphere will increase the fall-out rate, thus reducing the total atmospheric concentration of particles. Soil and water may be contaminated with particulate matter and other exhaust gas chemicals indirectly by dry and wet deposition (WHO, 1996).

<u>Evaluation Question #5:</u> Describe the toxicity and mode of action of the substance and of its breakdown products and any contaminants. Describe the persistence and areas of concentration in the environment of the substance and its breakdown products (7 U.S.C. § 6518 (m) (2)).

The available data suggest that the acute toxicity of exhaust gas is moderate to low at concentrations typically encountered in the outdoor areas. Inhalation of diesel exhaust with particle content of 6 mg/m^3 for about four weeks altered lung function in treated guinea pigs and rats (WHO, 1996). Drastic decreases in body weight were not observed in mice, rats, hamsters, cats and monkeys after long-term inhalation of exhaust gas concentrations in air of 4 mg/m[3]; rather, dose related toxic effects included up to 400% increase in lung weight, inflammation of air sacs in the lung, and impairment of lung performance (WHO, 1996). Subchronic inhalation exposure to exhaust gas is not expected to have reproductive and developmental health effects in animals and humans. Data from long-term inhalation studies in rats demonstrated that exhaust gas exposure leads to carcinogenesis at particle concentrations greater than 2 mg/m[3] (WHO, 1996). Despite the inherent carcinogenicity of polycyclic aromatic hydrocarbons (PAHs), *in vitro* genotoxicity tests and long-term inhalation exposure studies in rats do not support PAHs as the primary carcinogenic agent in exhaust gas mixtures.

Although gasoline engines primarily produce carbon dioxide (CO_2) and vaporized water (H_2O), specialized engines used in rodent control devices also generate small amounts of the incomplete combustion product carbon monoxide (CO). Exposure to CO_2 and CO can be hazardous, particularly in areas that are poorly ventilated. Applying a positive pressure of CO_2 will displace oxygen, thus causing hypoxia (oxygen deprivation) or anoxia (complete loss of oxygen) in humans and other organisms in the immediate area. Moderate CO_2-induced oxygen deprivation may cause headaches, dizziness, restlessness, tingling (pins and needles sensation), difficulty breathing, sweating, tiredness, increased heart rate and elevated blood pressure. More severe cases of CO_2-induced oxygen deprivation can cause a coma or death (WI DHFS, 2013). The toxic mode of action for CO involves inhibition of the ability of red blood cells to carry oxygen in the blood. Exposure to moderate concentrations of CO (200 parts per million) can cause headache, fatigue, chest pain, difficulty breathing, blurred vision, confusion, dizziness, nausea and vomiting, whereas exposure to high CO levels (greater than 1,200 parts per million) can induce coma or result in death within minutes (ATSDR, 2012; NIST, 2008; LARA, 2011). Exhaust gas devices must emit enough gas to displace oxygen in the burrow and engulf the target rodent in the CO-containing gas. There are no indications that humans operating the device would be at risk of asphyxiation or other adverse effects from CO/CO_2 exposure since the gas is applied underground and is likely to dissipate into the soil or outdoor air upon escape from the treated burrow.

Exhaust gas treatments in rodent burrows will lead to the poisoning of a wide array of non-target wildlife, including endangered and sensitive species, if present in treated areas. Many species of reptiles and amphibians, as well as burrowing owls, use the burrows of ground squirrels and other burrowing animals (CBD, 2011). In addition, non-target rodents, rabbits, raccoons, fox, weasel and skunk may reside in rodent burrows (USDA, 1997). According to the Center for Biological Diversity, endangered and sensitive species such as the Alameda whipsnake, California red-legged frog, San Francisco garter snake, San Joaquin kit fox, western burrowing owl and California tiger salamander often occupy rodent burrows and could be killed as a result of exhaust gas/carbon monoxide treatments (CBD, 2011). Because burrow fumigants will kill all animals residing in treated burrows, it is important to verify that target animals occupy the burrows before conducting the fumigation (USDA, 1997).

<u>Evaluation Question #6:</u> Describe any environmental contamination that could result from the petitioned substance's manufacture, use, misuse, or disposal (7 U.S.C. § 6518 (m) (3)).

High volume releases of exhaust gases to the atmosphere are associated with a variety of adverse environmental impacts. Specifically, exhaust gas emissions contribute to air pollution, and four of its components (particulate matter, carbon monoxide, nitrogen oxides and sulfur dioxide) are criteria pollutants according to US EPA (2012). Summarized below are the primary environmental impacts associated with the constituent chemicals of exhaust gas.

Carbon dioxide is the primary greenhouse gas emitted through human activities, such as the burning of gasoline and diesel in internal combustion engines, and associated with global climate change. Although CO_2 emissions come from a variety of natural sources, human-related emissions are responsible for the increased atmospheric CO_2 concentrations and corresponding impacts on the Earth's carbon cycle (US EPA, 2014). In addition to climate change issues, increased CO_2 concentrations are correlated with ocean acidification and related impacts on marine species, such as coral, shellfish, and pteropods (NOAA, undated). The nitrogen oxide compound nitrogen dioxide (NO_2) is an air pollutant, reacts in the atmosphere to form tropospheric ozone (O_3), and is therefore a significant contributor to photochemical smog formation. Although nitric oxide (NO) is the major NO_X emitted in exhaust gas, NO is readily reacts with free radicals in the atmosphere (created by photochemical reactions of volatile organic compounds) to generate NO_2 and therefore O_3. Molecules of the NO_X compound nitrous oxide (N_2O) can remain in the atmosphere for 100–150 years or more and have a 100-year global warming potential of over 300 times that of CO_2 (US EPA, 2014; US EPA, 1999). It should be noted that the primary source of atmospheric NO_2 is the agricultural application of synthetic fertilizers (US EPA, 2014). NO_X and sulfur oxide (SO_X) in the atmosphere are captured by moisture to form acid rain as nitric acid and sulfuric acid, respectively (Alberta, 2003; US EPA, 1999).

It is important to consider that exhaust gas volumes originating from underground rodent control would be considered negligible in comparison to the volumes released on farms due to the use of mechanized equipment powered with gasoline-powered internal combustion engines. Therefore, the contribution of exhaust gas emissions from rodent control devices to global environmental impacts of greenhouse gas emissions, photochemical smog and acid rain formation are not the key factor in determining the compatibility of exhaust gas rodent control with organic crop production.

Misuse, incorrect storage, or accidents (e.g., during transportation) involving the gasoline used to generate exhaust gas for rodent control may result in fire or explosions due to the flammability of gasoline and its reactivity with oxygen. These concerns are equally relevant to the widespread use of gasoline in internal combustion engines used to power equipment for organic crop production.

Evaluation Question #7: Describe any known chemical interactions between the petitioned substance and other substances used in organic crop or livestock production or handling. Describe any environmental or human health effects from these chemical interactions (7 U.S.C. § 6518 (m) (1)).

The primary constituents of exhaust gas mixtures, including nitrogen (N_2), carbon dioxide (CO_2) and water vapor (H_2O), as well the minor incomplete combustion product, carbon monoxide (CO), are relatively unreactive in the agricultural ecosystem. Plants absorb CO_2 from the atmosphere for use in photosynthesis and nitrogen oxides (NO_X) can be converted to nitrate (NO_3^-) fertilizer in the presence of moist soil (HSDB, 2010a; US EPA, 1999). However, no interactions between exhaust gas or its component chemicals and other common substances used in agriculture were identified.

Evaluation Question #8: Describe any effects of the petitioned substance on biological or chemical interactions in the agro-ecosystem, including physiological effects on soil organisms (including the salt index and solubility of the soil), crops, and livestock (7 U.S.C. § 6518 (m) (5)).

Exhaust gas is petitioned for use in underground rodent control, and would be released from the treated burrow following use. Rodent control using exhaust gas systems operates through the expulsion of air from rodent tunnels and replacement of the air with exhaust gas containing carbon monoxide (CO) and carbon dioxide (CO_2) (H&M, 2012). While CO diminishes the oxygen carrying capacity of red blood cells in the target rodent (NIST, 2008), the CO_2 content of exhaust gas removes oxygen from the atmosphere of the burrow and leads to asphyxiation of the rodent (WI DHFS, 2013). Any target mammals in the burrows feel the effects of exhaust gas simultaneously; the poisonous chemicals in exhaust gas are equally effective at killing adult and young rodents. However, because the toxic mode of action involves oxygen deprivation using volatile compounds, there is no risk of secondary poisoning to mammals and birds that feed on the carcasses of poisoned rodents.

Non-target animals may also dwell underground and be exposed to exhaust gas following its release in the treated area. Potentially affected non-target animals include other mammals, birds, reptiles, amphibians, invertebrates (e.g., bumble bees and earthworms), slugs, snails, protozoa and nematodes. Limited data is available regarding the effects of exhaust gas on soil organisms. Although large amounts of biofuel, diesel or associated exhaust gases may adversely affect the activity of soil microorganisms (Hawrot-Paw, 2011), a few reports have provided evidence that exhaust gas applications to soil may enhance the productivity of crops in treated areas (Heard, 2013; Boy, 2012). Indeed, plants may benefit from the carbon, nitrogen, oxygen and sulfur content of exhaust gas; however, the exposure of succulent, broad-leaved plants to sulfur dioxide (SO_2) present in some exhaust gases and its byproduct sulfuric acid (H_2SO_4) could result in dry, papery blotches that appear white, tan or straw-colored (Sikora, 2004). It is unlikely that SO_2 injury to plants will occur from the negligible (or even nonexistent) production of SO_2 in gasoline-based exhaust gas used in rodent control devices.

While only small amounts of NO_X and SO_X are released in the exhaust gases used for rodent control, these components may lead to localized acidic soil conditions when exposed to moisture in soils. For example, the acid generated from gaseous SO_2 can effectively mobilize metal ions (calcium, potassium, and magnesium) to lower inaccessible subsoil (Ophardt, 2003). This leaching process renders these and other essential metal ions inaccessible as nutrients or fertilizers for tree and plant growth. Increasing acid concentrations (i.e., lower pH soils) can also mobilize aluminum ions (Ophardt, 2003). Aluminum in neutral or slightly alkaline soils (pH greater than seven) is present in the insoluble and nontoxic form of aluminum hydroxide; however, when the soil pH drops to five or lower, aluminum ions are dissolved and become a source of toxicity for plants. In addition to stunting the growth of plant roots, lower soil pH and aluminum mobilization can reduce populations of soil microorganisms required for decaying leaves and other plant debris (Ophardt, 2003). Therefore, although NO_X and SO_X in exhaust gas mixtures may adversely impact soil chemistry, plants and soil microorganisms, these potential effects are unlikely due to the small amounts generated in rodent control devices.

As discussed in Evaluation Question #5, endangered species in agroecosystems would be at risk due to exhaust gas applications. For example, endangered and sensitive species such as the Alameda whipsnake, California red-legged frog, San Francisco garter snake, San Joaquin kit fox, western burrowing owl and California tiger salamander often occupy rodent burrows and could be killed as a result of exhaust gas/carbon monoxide treatments (CBD, 2011).

<u>Evaluation Question #9:</u> Discuss and summarize findings on whether the use of the petitioned substance may be harmful to the environment (7 U.S.C. § 6517 (c) (1) (A) (i) and 7 U.S.C. § 6517 (c) (2) (A) (i)).

Many of the constituent chemicals in exhaust gas are both persistent in the atmosphere and exhibit toxicity when released in the environment. Carbon dioxide (CO_2), a major component of exhaust gas, is long-lived with an atmospheric half-life ranging from 20–100 years (Moore, 1994), while the minor components carbon monoxide (CO) and nitrous oxide (N_2O) have respective atmospheric half-lives of two months and 100–150 years (ATSDR, 2012; HSDB, 2010a). CO_2 is the primary greenhouse gas emitted through human activities, and enhanced absorption of atmospheric CO_2 by the oceans leads to ocean acidification, which threatens numerous aquatic species. Nitrogen oxides (NO_X), minor components of exhaust gas, are both greenhouse gases and air pollutants contributing to climate change and formation of photochemical smog (US EPA, 1999). Atmospheric NO_X and sulfur dioxides (SO_X) originating from the exhaust gas of some engines are also responsible for the formation of acid rain (Alberta, 2003; US EPA, 1999). If SO_X such as SO_2 are present in the exhaust gas, repeated treatments to burrows in moist soil could lead to low soil pH levels and concomitant leaching of soil micronutrients and dissolution of aluminum compounds that are toxic to plants (Ophardt, 2003).

Despite the inherent toxicity and environmental impacts of exhaust gas chemicals, it is unlikely that the petitioned use of exhaust gas will lead to toxic effects outside of the treated burrow or environmental impairment on a similar scale to global transportation emissions. Indeed, exhaust gas emissions from internal combustion engines used to power farm equipment in conventional as well as organic operations contribute to adverse health effects and environmental impairments to a greater extent than exhaust gas emissions from rodent control devices. There is no indication that above ground animals would be at risk of asphyxiation or other adverse health effects from CO/CO_2 exposure since the gas is applied underground and are likely to dissipate into the soil or outdoor air upon escape from the treated burrow. Because exhaust gas is a nonspecific toxicant, however, exhaust gas treatments will lead to the poisoning of non-target wildlife residing in burrows. Reptiles, amphibians, and rabbits, as well as endangered and threatened species such as the California red-legged frog and the San Joaquin kit fox would be killed as a result of exhaust gas treatments to burrows in which they reside. Natural predators that inhabit the burrows of target rodents (e.g., snakes and burrowing owls) would be at risk from exhaust gas treatments.

<u>Evaluation Question #10:</u> Describe and summarize any reported effects upon human health from use of the petitioned substance (7 U.S.C. § 6517 (c) (1) (A) (i), 7 U.S.C. § 6517 (c) (2) (A) (i)) and 7 U.S.C. § 6518 (m) (4)).

Acute toxicity in humans is a concern for exhaust gas containing carbon dioxide (CO_2) and carbon monoxide (CO), particularly in areas that are poorly ventilated. Applying a positive pressure of CO_2 will displace oxygen, thus causing hypoxia (oxygen deprivation) or anoxia (complete loss of oxygen) in humans and other organisms in the immediate area. Moderate CO_2-induced oxygen deprivation may cause headaches, dizziness, restlessness, tingling (pins and needles sensation), difficulty breathing, sweating, tiredness, increased heart rate and elevated blood pressure. More severe cases of CO_2-induced oxygen deprivation can cause a coma or death (WI DHFS, 2013). The toxic mode of action for CO involves inhibition of the ability of red blood cells to carry oxygen in the blood. Exposure to moderate concentrations of CO can cause headache, fatigue, chest pain, difficulty breathing, blurred vision, confusion, dizziness, nausea and vomiting, whereas exposure to high CO levels can induce coma or result in death within minutes (ATSDR, 2012; NIST, 2008). Acute exposure to diesel exhaust gas has been associated with irritation of mucous membranes in the eyes, nose and throat (WHO, 1996).

Subchronic and chronic toxicity in humans from various exhaust gases is also possible. Inhalation of diesel exhaust may lead to inflammation of air sacs in the lung and associated impairment of lung performance (WHO, 1996). In contrast, subchronic inhalation exposure to exhaust gas is not expected to have reproductive and developmental health effects in humans. Data from long-term inhalation studies in rats demonstrated that exhaust gas exposure leads to carcinogenesis at particle concentrations greater than 2 mg/m^3 (WHO, 1996). Further, epidemiological studies in humans have found a positive correlation between increased diesel exhaust gas exposure and the incidence of lung cancer (WHO, 1996). According to the International Agency for Research on Cancer and California Proposition 65 list, diesel exhaust gas is carcinogenic to humans (IARC, 2014; OEHHA, 2014). Gasoline exhaust gas is possibly carcinogenic to humans (IARC category 2B), while the minor component sulfur dioxide (SO_2) is not classifiable as to its carcinogenicity to humans (IARC category 3) (IARC, 2014). Despite the inherent carcinogenicity of polycyclic aromatic hydrocarbons (PAHs), *in vitro* genotoxicity tests and long-term inhalation exposure studies in rats do not support PAHs as the primary carcinogenic agent in exhaust gas mixtures (WHO, 1996). Concerns have been noted regarding the potential human health impacts of benzene, a known human carcinogen and component of the unreacted hydrocarbons in exhaust gas (WHO, 2010; IARC, 2014).

As discussed above, acute and chronic exposure to exhaust gas can lead to a variety of toxic effects in humans. However, the contribution of rodent control exhaust gas to the aggregate toxicity of exhaust gases produced in internal combustion engines used to power automobiles, modern farming equipment and other machines is likely to be negligible. There is no indication that applicators, farmworkers and residential bystanders would be at risk of asphyxiation or other adverse health effects from exhaust gas exposure since the gaseous mixture is applied underground and is likely to dissipate into the soil or outdoor air upon escape from the treated burrow. With respect to CO, acute toxicity depends on both the concentration of CO in the air and the duration of exposure (HSDB, 2010b). As such, the Occupational Safety and Health Administration (OSHA) set a legal limit of 55 parts per million (ppm) for CO in air for an 8-hour work day, 40 hours per workweek (ATSDR, 2012). Data provided in the petition indicates that short-term (five to ten minutes) CO exposure during exhaust gas treatments should not exceed 30 ppm in the vicinity of applicators and bystanders (H&M, 2012).

Evaluation Question #11: Describe all natural (non-synthetic) substances or products which may be used in place of a petitioned substance (7 U.S.C. § 6517 (c) (1) (A) (ii)). Provide a list of allowed substances that may be used in place of the petitioned substance (7 U.S.C. § 6518 (m) (6)).

While several synthetic substances are available for use in rodent control applications, the National Sustainable Agriculture Information Service does not generally encourage the use of many of these chemical controls (ATTRA, 2014). Anticoagulant rodenticides are widely used in residential and agricultural settings for rodent control, but are not approved by the NOP for use in organic farming. First-generation anticoagulant rodenticides, including chlorophacinone, diphacinone and warfarin, require rodents to consume the bait for several consecutive feedings for delivery of a lethal dose (Erickson & Urban, 2004). In contrast, second-generation rodenticides, including brodifacoum, bromadiolone, difethialone and difenacoum, are substantially more potent than the first-generation rodenticides (Erickson & Urban, 2004). Ingestion of a lethal dose can occur after just one feeding. First- and second-generation rodenticides have moderate to high potential to poison non-target animals directly or through the ingestion of poisoned rodents. Non-anticoagulant substances such as bromethalin, cholecalciferol and zinc phosphide have highly variable potencies, with rodent mortalities typically occurring several hours (zinc phosphide) to days (cholecalciferol) following ingestion of a lethal dose (Erickson & Urban, 2004). A lower secondary poisoning potential is estimated for these substances relative to anticoagulant rodenticides.

Vitamin D_3 (cholecalciferol) is a synthetic substance included on the National List for use in crop production as a rodenticide (7 CFR 205.601(g)), and is the active ingredient in some commercially available rodenticide baits. Rodenticides containing cholecalciferol produce hypercalcemia (i.e., excessive levels of calcium in the blood). Rodents generally die within two days following ingestion of a lethal dose and do not exhibit bait shyness (ATTRA, 2014; USDA, 2011a). Care should be exercised when placing bait, particularly where pets are present, due to the potential for primary poisoning through unintentional ingestion of loose baits (ATTRA, 2010). The National List states that vitamin D_3 cannot be the sole means of rodent control and requires operators to document alternative methods in their Organic System Plan. Growers must take precautions to prevent killing non-target animals (7 CFR 205.271; 7 CFR 205.601(g)).

According to the Organic Materials Research Institute, currently registered products containing vitamin D_3 for use in organic crop production include (OMRI, 2014):

- Agrid3® Bait Chunx® (Motomco/Bell Laboratories, Inc.)
- Agrid3® Pelleted Bait (Motomco/Bell Laboratories, Inc.)
- Terad3® Ag Blox (Bell Laboratories, Inc.)

Injection of carbon dioxide (CO_2) into burrows is a potential alternative to exhaust gas for rodent control. CO_2 is heavier than air (HSDB, 2010a), and should therefore sink to the bottom of the burrow, displacing oxygen and suffocating the target animals in the treated area. However, information is not readily available on whether CO_2 would remain at high enough concentrations for a sufficient period of time once injected into the burrow to kill the target rodents. Commercially available sources of CO_2 are generally derived as byproducts of industrial processes such as the production of ammonia (NH_3) and hydrogen (H_2). Physical and chemical processes must also be used to extract naturally occurring CO_2 from natural gas wells (Pierantozzi, 2003). CO_2 may be considered a synthetic substance since chemical methods are used to process both synthetic and naturally occurring sources of the substance.

Sulfur dioxide used in commercial smoke bombs for underground rodent control was previously allowed as a rodenticide under 7 CFR 205.601(g). However, the National Organic Program removed the substance from the National List in 2012 according to recommendations from the National Organic Standards Board's sunset review (USDA, 2011b).

No other chemical alternatives to the petitioned substance were identified. Physical control methods are described below in Evaluation Question #12.

<u>Evaluation Question #12:</u> Describe any alternative practices that would make the use of the petitioned substance unnecessary (7 U.S.C. § 6518 (m) (6)).

Burrowing rodent populations can be effectively controlled in agricultural and residential settings using traps, barriers, natural predation, as well as other physical control methods. The paragraphs below provide details on the use and efficacy of these alternative rodent control strategies.

Traps and Barriers

According to ATTRA, many if not most organic farmers rely on trapping for some degree of rodent control. Rodent traps provide clear confirmation of a captured rodent as well as an effective alternative to rodent poisons and burrow fumigants that are also toxic to non-target wildlife through primary (direct exposure/ingestion) and secondary (consumption of poisoned rodent) exposure to toxic rodenticides. Although the efficacy of traps varies among different pest vertebrates, one study found that live trapping using a wooden bait box filled with non-poisonous peeled oat controlled rodent populations to the same extent as rodenticide treatments on ten farms (Meerberg, 2006). Persistence, skill and appropriate traps are required for the successful control of rodents using trapping techniques. Trapping must be performed daily, especially during critical times in the growing season and the life cycle of the rodent (ATTRA, 2014). Cage traps can be used to capture individual animals, but the process is typically too expensive and time consuming to be employed for some vertebrate pests such as the prairie dog control. Best results are obtained by trapping in early spring after snowmelt and before pasture green up. Bait traps consisting of oats flavored with corn oil or anise oil are recommended for prairie dogs (Hygnstrom & Virchow, 2005).

Making the farm and areas around the farm buildings less hospitable to rodents through the removal of shelter and food sources can help minimize the occurrence of rodent problems. Fences, wire baskets, as well as trenches and irrigation can serve as barriers to the invasion of rodents and their access to food (ATTRA, 2014). Exclusion methods may not work equally well for all vertebrate pests. For example, prairie dogs are rarely controlled using exclusion, but may be discouraged by tight-mesh, heavy-gauge, galvanized wire, five feet wide with two feet buried in the ground and three feet remaining aboveground. Because prairie dogs prefer to maintain a clear view of their surroundings and potential predators, fences, hay bales and other objects can be used to block prairie dogs' view and therefore reduce the suitability of the habitat (Hygnstrom & Virchow, 2005). Plants such as gopher purge (*Euphorbia lathyrus*), castor bean (*Ricinus communis*) and garlic have been suggested as natural plant repellents around fields and in gardens, although effective control has not been demonstrated in the literature (Salmon & Baldwin, 2009). In addition, Day Jessamine (*Cestrum diurnum*) and *Solanum malacoxylon* plants are natural sources of cholecalciferol (ATTRA, 2014).

Natural Predators

Natural predators such as gopher snakes, corn snakes, rat snakes, owls, hawks, great blue herons, weasels, bobcats, coyotes, and domestic dogs and cats can help to control rodent populations by killing and/or feeding on rats, mice and burrowing rodents (ATTRA, 2014). The corn snake (*Elaphe guttata*) and rat snake (*Elaphe obsolete*) are two species of rat snakes commonly found on the US mainland that feed on mice, rats and squirrels (ATTRA, 2014). In addition to rodents, chicks and eggs may also be at risk since rat snakes also feed on small birds. Barn owls are also efficient rodent hunters. With more than 95 percent of their diet consisting of small mammals, each adult barn owl may consume one or two rodents per night, and a family of barn owls can eat more than 1,000 rodents per year (ATTRA, 2014). Installation of custom made or commercially available nesting boxes can encourage barn owls to nest and stay near the target area. Organizations such as the Hungry Owl Project can provide fully constructed nesting boxes for agricultural and residential use (Hungry Owl, 2013). Strategic placement of nesting boxes with the use of traps and other preventative measures can significantly improve pest rodent problems.

Other Methods

Physical methods of rodent removal can also effectively mitigate rodent problems in combination with other strategies. Flooding burrows and tunnels with large amounts of water using a garden hose is recommended in some situations. However, the operator must be careful to avoid flooding near underground structures of building foundations to avoid damage (Cleary & Craven, 2005). Shooting rodents is selective and nonhazardous to other wildlife in the area. For prairie dogs, this practice is most effective in spring because it can disrupt their breeding pattern. Continuous shooting can remove up to 65% of their population during the year, but is time consuming and therefore not practical or cost-effective. Some animals, such as prairie dogs, often become gun-shy after extended periods of shooting (Hygnstrom & Virchow, 2005).

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